Continued Study of Parallel Events

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Motivation

- The time resolution of a LArTPC is finite, ionization within the same time slice is degenerate
- Particle tracks that are near parallel to the wire plane become degenerate
- Background events that occur near parallel can be incorrectly identified as signal
- Neutral pion decay produces γ and $e^{\pm}$ (significant background)
- Signal events that produce charged hadrons parallel to wire plane can also increase problems to reconstruction
- If the wire plane is rotated to be perpendicular to the beam, most degeneracies should be avoided

  $\rightarrow$ Want to know how many problematic background and signal events to expect, relative to "good" signal events using various "problematic" angle cuts and two wire plane configurations

Fast MC

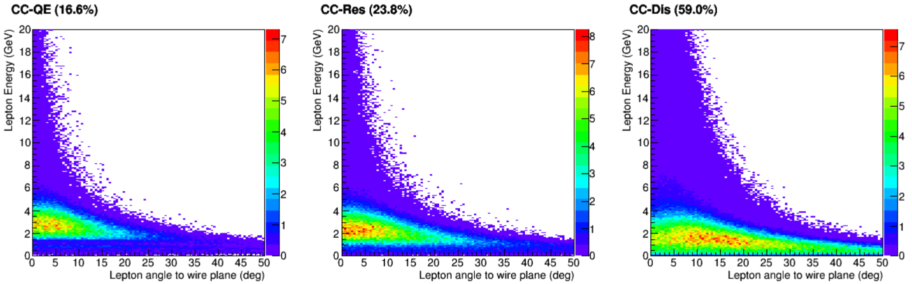
http://www.phy.bnl.gov/bviren/data/fmcfiles/fastmcNtp_20140711_lbne_g4lbnev3r2p4_nuflux_numuflux_nue_LAr_1_g280_Ar40_5000_Default.root

- Used $\nu_\mu \to \nu_e$ Fast MC (10^6 events) to simulate CC signal events and CC π^0 decay backgrounds

http://www.phy.bnl.gov/bviren/data/fmcfiles/fastmcNtp_20140711_lbne_g4lbnev3r2p4_nuflux_numuflux_numu_LAr_1_g280_Ar40_5000_Default.root

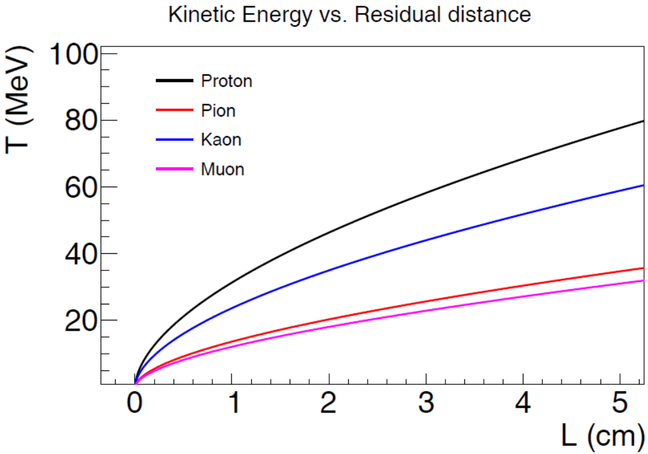
- Used $\nu_\mu \to \nu_\mu$ Fast MC (10^6 events) to simulate NC π^0 decay backgrounds
- In order to compare results between files, use POTWeight and OSCWeight
- Assume detector mass of 34 kT, exposure time 3 years, 1.1×10^{21} POT/year
- Nominal problematic track angle taken to be 7.5° w.r.t. wire plane. Also consider 5.0 and 2.5°.

Lepton Energy Cut



- Shows the number of CC signal events as a function of lepton energy and angle to the wire plane
- High energy leptons are highly parallel
- Greatest intensity is $E_e < 6$ GeV, focus on this region for study (apply this cut for all CC events)

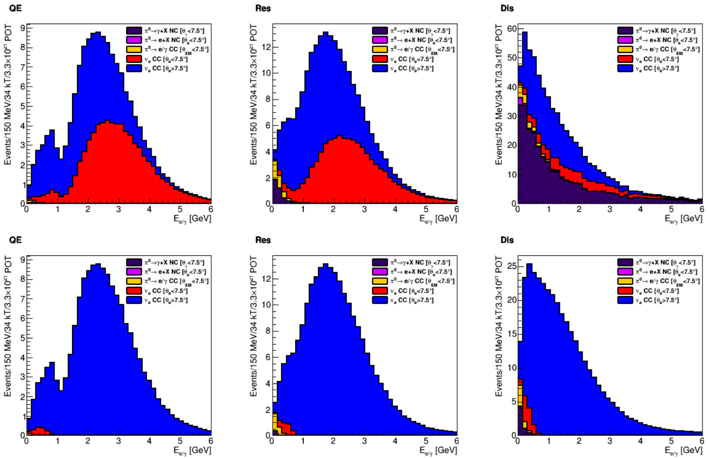
Final State Hadrons in Signal Events



- Hadrons that don't travel more than 1.5 cm shouldn't shadow electron tracks
- Hadrons that don't travel more than 5 cm won't make γ NC backgrounds harder to reconstruct
- Low energy threshold (1.5cm track length) of 17.5, 30, and 39 MeV for pion, kaon, and proton, respectively
- High energy threshold (5 cm track lengths) of 35, 58.5, and 78 MeV for pion, kaon, and proton, respectively

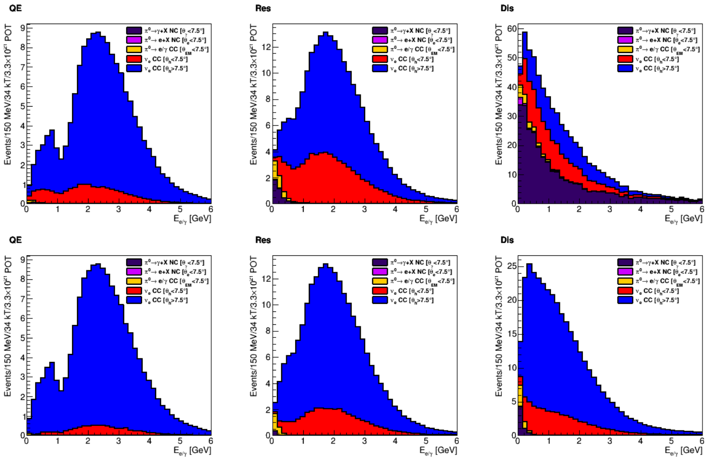
Identify Problematic Events

- For each CC signal event, compute lepton angle and smallest hadron angle w.r.t. wire plane of final state hadrons
  - Do not consider tracks from neutrons, neutral pions, and photons. Do not consider hadrons with energy less than the defined threshold
- For each CC signal event, compute lepton angle and smallest final state EM angle to wire plane. If the particle is a photon, simulate conversion length using TRandom3::Exp() (only consider photons problematic if they decay within 3cm)
- For each NC event, pick the EM final state that has the smallest angle to the wire plane subject to the following selection criteria. If particle is electron, check that there is a final state pion that is within the defined angle to wire plane and traveling in the same direction (away from or toward the wire plane). If final state is photon, require that the conversion length is between 1 and 5 cm and there is a final state hadron passing the high energy thresholds traveling within the specified angle on the same side as the photon.



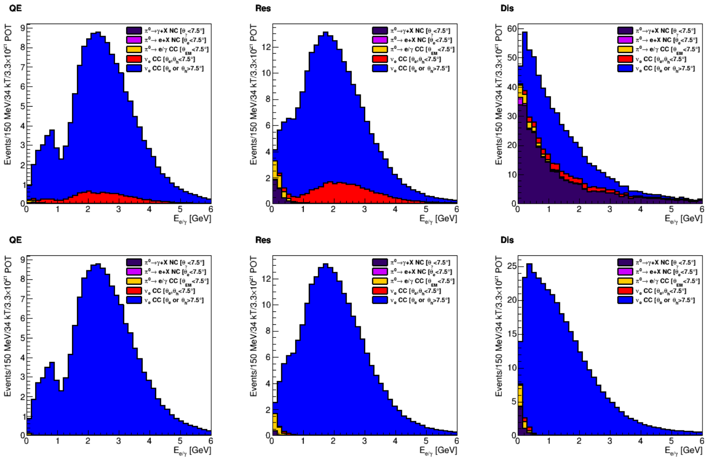
- Standard (perpendicular) wire configuration on top (bottom)
- Consider CC signal events problematic when lepton angle is less than nominal (otherwise, signal is "good")
- Event rate as function of particle energy (true e in signal, misID'd γ or e in background)
- θ_{EM} is minimum angle that a background e/γ makes with wire plane
- DIS is most problematic, significant reduction by rotating wire plane

Nominal Angle Cut, Hadron Angle



- Standard (perpendicular) wire configuration on top (bottom)
- Consider CC signal events problematic when minimum hadron angle is less than nominal (otherwise, signal is "good")
- Event rate as function of particle energy (true e in signal, misID'd γ or e in background)
- θ_{EM} is minimum angle that a background e/γ makes with wire plane
- DIS is most problematic, moderate reduction by rotating wire plane

Nominal Angle Cut, Lepton and Hadron Angle



- Standard (perpendicular) wire configuration on top (bottom)
- Consider CC signal events problematic when lepton and minimum hadron angle on lepton side are less than nominal (otherwise, signal is "good")
- Event rate as function of particle energy (true e in signal, misID'd γ or e in background)
- θ_{EM} is minimum angle that a background e/γ makes with wire plane
- DIS is most problematic case, significant reduction by rotating wire plane

Nominal Angle Cut

	Standard Configuration			Rotated Configuration		
	QE	Res	DIS	QE	Res	DIS
NC $\pi^0 \to \gamma + X$	0.1	3.8	287.4	~ 0	0.4	5.7
NC $\pi^0 \to e + X$	~ 0	0.1	6.5	~ 0	0.03	0.1
CC EM	0.4	3.3	16.5	0.1	2.1	4.4
Parallel Signal (θ_e)	70.5	88.0	83.4	1.5	2.7	9.9
Good Signal (θ_e)	79.2	131.2	259.0	148.9	216.6	332.5
Parallel Signal (θ_h)	18.3	66.9	159.6	8.6	35.8	59.1
Good Signal (θ_h)	132.1	152.3	182.9	141.8	183.4	283.3
Parallel Signal (θ_e, θ_h)	10.2	27.6	38.9	0.06	0.4	1.6
Good Signal (θ_e, θ_h)	140.1	191.6	303.6	150.3	218.8	340.9

- NC π^0 decay constitutes a major background in DIS in standard configuration
- Change in wire plane configuration has the greatest effect when good signal is defined with respect to electron angle, since lepton is mostly forward while hadrons are produced more isotropically
- Rotating wire plane yields significant improvement in proportional rate of usable signal

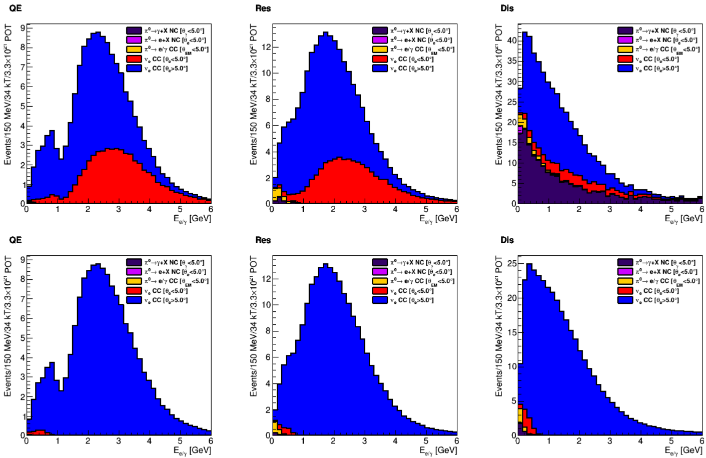
Nominal Angle Cut

Breakdown of NC cuts:

Cut	1	2	3	3.1	4	4.1	4.2	3.1 & 4.2
Standard	8322.4	3805.7	24.1	7.8	1879.5	525.6	244.5	1.6
Perpendicular			5.8	0.2	586.0	119.8	7.0	~ 0

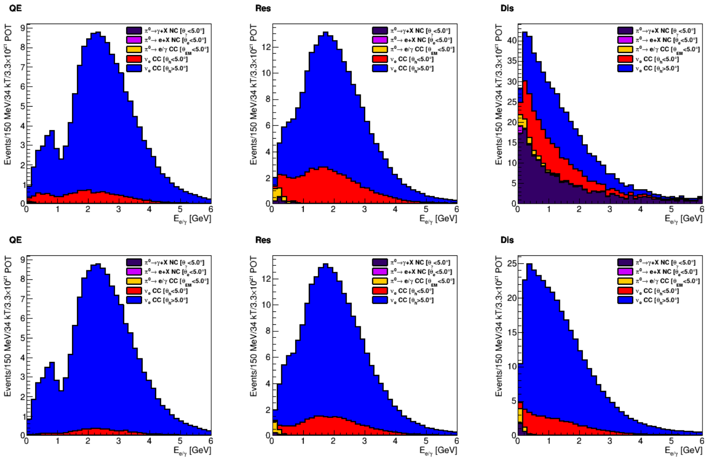
- Cut 1: Total NC events (QE, Res, or Dis) with $E_{e/\gamma} < 6$ GeV
- Cut 2: NC events with final state π^0 (true for all following)
- Cut 3: Has e with $\theta_e < 7.5^\circ$
- Cut 3.1 Has e with $\theta_e < 7.5^\circ$ and has $\pi^\pm$ with $\theta_{\pi^\pm} < 7.5^\circ$
- Cut 4: Has γ with $\theta_\gamma < 7.5^\circ$
- Cut 4.1: Has γ with $\theta_\gamma < 7.5^\circ$ within conversion length range 1-5 cm
- Cut 4.2: Has γ with $\theta_\gamma < 7.5^\circ$ within conversion length range 1-5 cm and has hadron with $\theta_h < 7.5^\circ$ passing high energy threshold
- Sum of 3.1 and 4.2 (minus 3.1 & 4.2) is slightly smaller (larger) than the total NC backgrounds in the parallel (perpendicular) configuration. Suspected to be because of random number generation for γ conversion length, but this consistent behavior for all angles mandates a second look.

5° Angle Cut, Lepton Angle

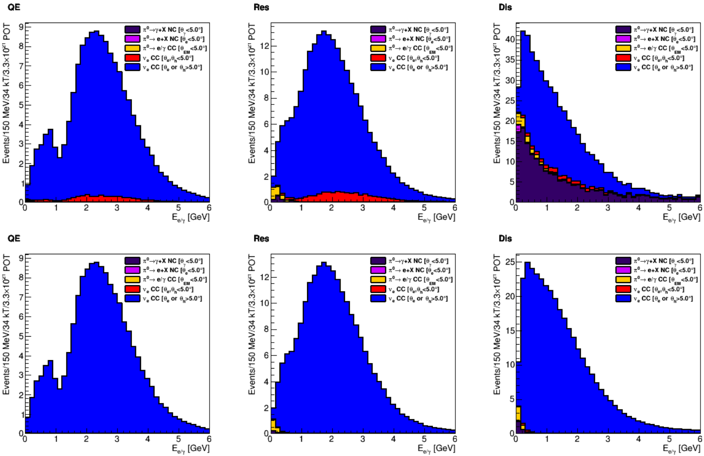


- Standard (perpendicular) wire configuration on top (bottom)
- Consider CC signal events problematic when lepton angle is less than 5° (otherwise, signal is "good")
- Event rate as function of particle energy (true e in signal, misID'd γ or e in background)
- θ_{EM} is minimum angle that a background e/γ makes with wire plane
- DIS is most problematic, significant reduction by rotating wire plane

5° Angle Cut, Hadron Angle



- Standard (perpendicular) wire configuration on top (bottom)
- Consider CC signal events problematic when minimum hadron angle is less than 5° (otherwise, signal is "good")
- Event rate as function of particle energy (true e in signal, misID'd γ or e in background)
- θ_{EM} is minimum angle that a background e/γ makes with wire plane
- DIS is most problematic, moderate reduction by rotating wire plane



- Standard (perpendicular) wire configuration on top (bottom)
- Consider CC signal events problematic when lepton and minimum hadron angle on lepton side are less than 5° (otherwise, signal is "good")
- Event rate as function of particle energy (true e in signal, misID'd γ or e in background)
- θ_{EM} is minimum angle that a background e/γ makes with wire plane
- DIS is most problematic, significant reduction by rotating wire plane

5° Angle Cut

	Standard Configuration			Rotated Configuration		
	QE	Res	DIS	QE	Res	DIS
NC $\pi^0 \to \gamma + X$	0.03	1.0	168.2	~ 0	0.3	2.4
NC $\pi^0 \to e + X$	~ 0	0.03	4.4	~ 0	0.03	0.07
CC EM	0.2	2.3	11.5	0.07	1.3	2.9
Parallel Signal (θ_e)	48.7	61.0	54.2	1.0	1.7	6.7
Good Signal (θ_e)	101.7	158.2	288.2	149.4	217.5	335.7
Parallel Signal (θ_h)	12.7	47.1	119.2	5.8	24.9	41.7
Good Signal (θ_h)	137.7	172.1	223.2	144.6	194.4	300.8
Parallel Signal (θ_e, θ_h)	5.9	13.8	19.1	0.03	0.2	0.7
Good Signal (θ_e, θ_h)	144.5	205.5	323.3	150.4	219.0	341.7

- Event rates for 34 kt on LAr, 3 yr exposure time, 1.1×10^{21} POT/yr
- NC π^0 decay constitutes a major background in DIS in standard configuration
- Change in wire plane configuration has the greatest effect when good signal is defined with respect to electron angle, since lepton is mostly forward while hadrons are produced more isotropically
- Rotating wire plane yields significant improvement in proportional rate of usable signal

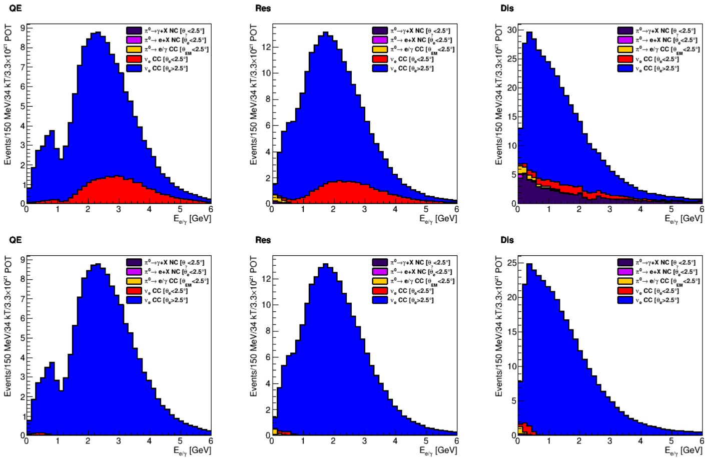
5.0° Angle Cut

Breakdown of NC cuts:

Cut	1	2	3	3.1	4	4.1	4.2	3.1 & 4.2
Standard	8322.4	3805.7	17.5	4.9	1468.6	380.8	149.1	0.9
Perpendicular			4.1	0.1	398.0	78.2	3.2	~ 0

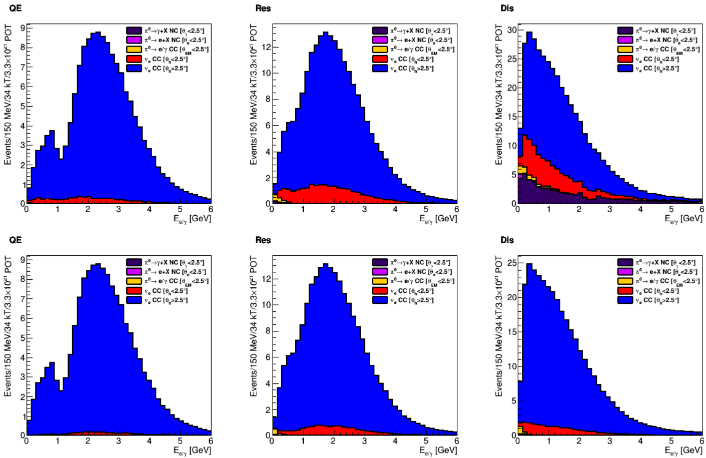
- Cut 1: Total NC events (QE, Res, or Dis) with $E_{e/\gamma} < 6$ GeV
- Cut 2: NC events with final state π^0 (true for all following)
- Cut 3: Has e with $\theta_e < 5.0^\circ$
- Cut 3.1 Has e with $\theta_e < 5.0^\circ$ and has $\pi^\pm$ with $\theta_{\pi^\pm} < 5.0^\circ$
- Cut 4: Has γ with $\theta_\gamma < 5.0^\circ$
- Cut 4.1: Has γ with $\theta_\gamma < 5.0^\circ$ within conversion length range 1-5 cm
- Cut 4.2: Has γ with $\theta_\gamma < 5.0^\circ$ within conversion length range 1-5 cm and has hadron with $\theta_h < 5.0^\circ$ passing high energy threshold

2.5° Angle Cut, Lepton Angle



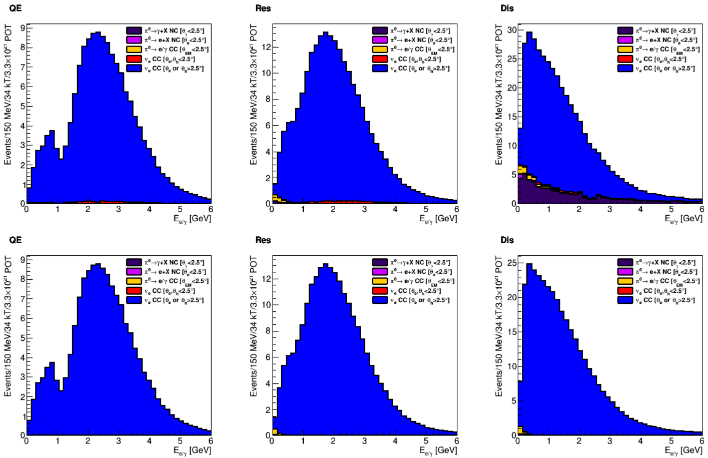
- Standard (perpendicular) wire configuration on top (bottom)
- Consider CC signal events problematic when lepton angle is less than 2.5° (otherwise, signal is "good")
- Event rate as function of particle energy (true e in signal, misID'd γ or e in background)
- θ_{EM} is minimum angle that a background e/γ makes with wire plane
- DIS is most problematic, significant reduction by rotating wire plane

2.5° Angle Cut, Hadron Angle



- Standard (perpendicular) wire configuration on top (bottom)
- Consider CC signal events problematic when minimum hadron angle is less than 2.5° (otherwise, signal is "good")
- Event rate as function of particle energy (true e in signal, misID'd γ or e in background)
- θ_{EM} is minimum angle that a background e/γ makes with wire plane
- DIS is most problematic, moderate reduction by rotating wire plane

2.5° Angle Cut, Lepton and Hadron Angle



- Standard (perpendicular) wire configuration on top (bottom)
- Consider CC signal events problematic when lepton and minimum hadron angle on lepton side are less than 2.5° (otherwise, signal is "good")
- Event rate as function of particle energy (true e in signal, misID'd γ or e in background)
- θ_{EM} is minimum angle that a background e/γ makes with wire plane
- DIS is most problematic, reduction by rotating wire plane

2.5° Angle Cut

	Standard Configuration			Rotated Configuration		
	QE	Res	DIS	QE	Res	DIS
NC $\pi^0 \to \gamma + X$	~ 0	0.4	54.1	~ 0	0.07	0.5
NC $\pi^0 \to e + X$	~ 0	0.03	2.0	~ 0	~ 0	0.03
CC EM	0.1	1.2	5.9	0.03	0.7	1.5
Parallel Signal (θ_e)	24.5	31.1	26.3	0.5	0.9	3.4
Good Signal (θ_e)	125.9	188.2	316.1	149.9	218.4	339.0
Parallel Signal (θ_h)	6.5	24.9	67.1	2.9	12.7	22.1
Good Signal (θ_h)	143.9	194.3	275.3	147.5	206.5	320.3
Parallel Signal (θ_e, θ_h)	2.1	3.7	5.4	0.01	0.05	0.2
Good Signal (θ_e, θ_h)	148.3	215.5	337.1	150.4	219.2	342.2

- Event rates for 34 kt on LAr, 3 yr exposure time, 1.1×10^{21} POT/yr
- NC π^0 decay constitutes the largest background in DIS in standard configuration
- Change in wire plane configuration has the greatest effect when good signal is defined with respect to electron angle, since lepton is mostly forward while hadrons are produced more isotropically
- Rotating wire plane yields greatest improvement in proportional rate of usable signal

2.5° Angle Cut

Breakdown of NC cuts:

Cut	1	2	3	3.1	4	4.1	4.2	3.1 & 4.2
Standard	8322.4	3805.7	10.6	2.1	896.5	206.0	53.2	0.2
Perpendicular			2.2	0.03	208.4	39.6	0.8	~ 0

- Cut 1: Total NC events (QE, Res, or Dis) with $E_{e/\gamma} < 6$ GeV
- Cut 2: NC events with final state π^0 (true for all following)
- Cut 3: Has e with $\theta_e < 2.5^\circ$
- Cut 3.1 Has e with $\theta_e < 2.5^\circ$ and has $\pi^\pm$ with $\theta_{\pi^\pm} < 2.5^\circ$
- Cut 4: Has γ with $\theta_\gamma < 2.5^\circ$
- Cut 4.1: Has γ with $\theta_\gamma < 2.5^\circ$ within conversion length range 1-5 cm
- Cut 4.2: Has γ with $\theta_\gamma < 2.5^\circ$ within conversion length range 1-5 cm and has hadron with $\theta_h < 2.5^\circ$ passing high energy threshold

Conclusions

- Electrons from CC events are largely forward, which leads to very frequent degenerate tracks. Rotating the wire plane eliminates degenerate electrons greater than ~ 1 GeV.
- Hadron production is more isotropic, especially in DIS. Rotating the wire plane does not eliminate hadron degeneracies as effectively, but there are fewer of them in the standard configuration to begin with
- EM NC background is persistent problem in standard wire plane configuration
- EM NC background is eliminated above $\sim 1GeV$ because final states of π^0 decay are forward produced
- There are very few events with hadron/electron degeneracies, irrespective of cutoff angle